Evaluation of Titanium Dioxide as a Catalyst for Removing Air Pollutants

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The Issue

Titanium dioxide (TiO_2) photocatalysis is a promising method for removing smog precursors from air. When TiO_2 nanoparticles are stimulated by sunlight, they convert air pollutants such as nitrogen oxides (NO_x), volatile organic compounds (VOCs), carbon monoxide (CO), and ozone to more environmentally acceptable products such as calcium nitrate and carbon dioxide.[1] TiO_2 photocatalysis can be driven by both the ultraviolet and visible components of sunlight, which comprise nearly 50% of ground-level insolation.

a) removal of air pollutants by adsorption during the night	b) removal of air pollutants by oxidation during the day	c) regeneration of photocatalyst by rainfall

Figure 1. Nitrous oxide (NO_X) and sulfur oxide (SO_X) pollutants adhere to the TiO_2 paint coating whether light is available or not. Sunlight then instigates a series of chemical reactions (see Figure 2) that convert the harmful pollutants to carbon dioxide and water vapor. The TiO_2 photocatalyst is regenerated by rainfall. (Figure courtesy of Koji Takeuchi, Institute for Environmental Management Technology, Japan.)

[1] Although carbon dioxide (CO_2) is a greenhouse gas, it is nontoxic, and as such represents a net air quality improvement over the precursor pollutants. Moreover, the CO_2 production is anticipated to be minimal and would be offset (to an unknown degree) by lower CO_2 emissions from power plants due to the reduced cooling load from buildings painted with the highly reflective TiO_2 coating.

Researchers have shown that it is technically feasible to coat glass, tiles, and other building materials with a transparent thin film of TiO_2 photocatalyst.[2,3] Hence, TiO_2 wall and roof coatings could be used to remove outdoor air pollutants. (As an interesting side benefit, windows coated with a thin, transparent layer of TiO_2 can self-clean.)

Project Description

This project—funded by PIER's Environmental Exploratory Grants Program—brought together leading international researchers to evaluate the potential for TiO_2 coatings to remove pollutants from urban air. Researchers from Lawrence Berkeley National Laboratory collaborated with the South Coast Air Quality Management District, the California Air Resources Board, and academic and industrial researchers to estimate the efficacy of TiO_2 photocatalysis in removing NO_x and VOCs. The project reviewed the laboratory methods and metrics used to measure removal of smog precursors (NO_x and VOCs) and carbon monoxide, and evaluated approaches to extend these methods and metrics to community and regional scales. The project team also worked with the coating industry to assess the commercial readiness of TiO_2 photocatalytic coatings. Findings were shared at a workshop with leading researchers and air quality agencies.

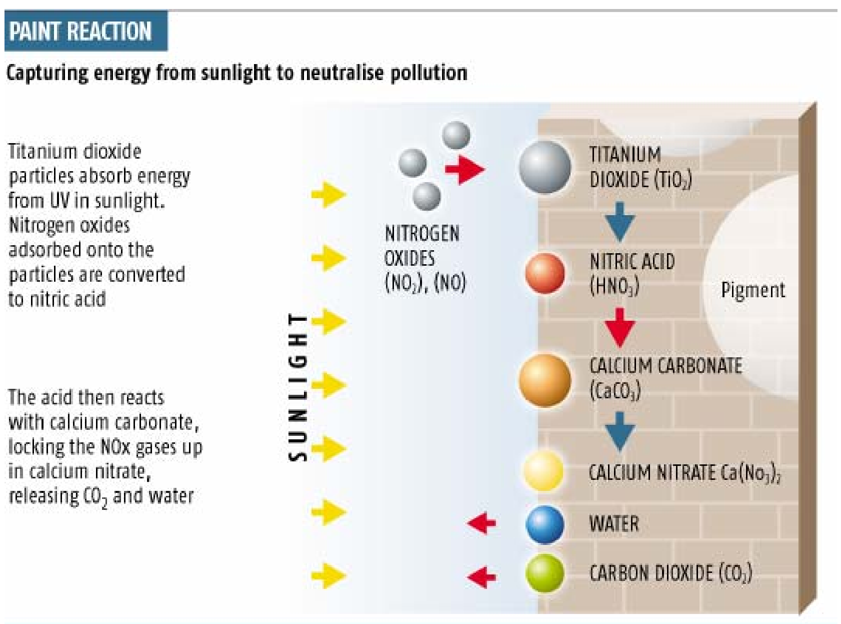

Figure 2. Outline of the pollutant-removal chemical reactions for a TiO_2 coating. (Courtesy of Hogan, *New Scientist*, February 4, 2004, http://www.newscientist.com/article.ns?id=dn4636.)

[2] Yu, C. M., W. K. Ho, et al. April 2003. Effects of Trifluoroacetic Acid Modification on the Surface Micro-structures and Photocatalytic Activity of Mesoporous TiO_2 Thin Films. *Langmuir* 19(9):3889–3896 (United States: American Chemical Society).

[3] Yu, C. M., W. U. Ling, et al. 2003. Microemulsion-Mediated Solvothermal Synthesis of Nanosized CdS-Sensitized TiO_2 Crystalline Photocatalyst. *Chemical Communications* 13:1552–1553 (United Kingdom: Royal Society of Chemistry).

PIER Program Objectives and Anticipated Benefits for California

This project offers numerous benefits and meets the following PIER program objectives:

- **Resolve environmental effects of energy production.** As a result of this work, it is clear that further research and analysis is required for widespread implementation of photocatalytic oxidation technology for cleaning outdoor air in California. With further innovation and development, TiO_2 nanoparticles or other photocatalytic coatings may prove a cost-effective means of reducing NO_X and VOCs (compare to SCAQMD's 2003 plan that cost $2,000–$10,000 per tonne of NO_X removed).
- **Provide affordable energy.** Many TiO_2-based coatings have high solar reflectance and can reduce electricity use for summertime cooling by keeping the building roofs and walls cool. Measured data have documented net annual energy savings (summertime cooling savings minus wintertime heating penalty) of 10%–20%.[4,5,6] A 10% reduction in annual cooling energy use would save about $50 per household each year, for an annual savings to California of about $50 million.[7]

Results

Following an extensive literature review, the LBNL project team hosted a day-long workshop on Passive Photocatalytic Oxidation of Air Pollution, at which participants discussed the technical state of the art in this field. The efficacy of photocatalytic materials was summarized and tabulated in terms of catalytic activity. Each square meter of high-performance photocatalytic material, exposed to outdoor sunlight, can remove nitrogen oxides from about 200 cubic meters of air per day. The removal rate for volatile organic species is about 60 cubic meters of air per day, while the removal rate for carbon monoxide is negligible. These numbers are rough estimates, but are based on careful quantitative investigations published in references cited by the final report.

Photocatalytic reduction of air pollution using TiO_2 nanoparticles is thus technically feasible; however, accomplishing this goal in a cost-effective way will be challenging due to the large volumes of air that must be processed. Apart from cost, choice of the best catalyst from a number of candidates will also depend on which chemical reactions (i.e., which pollutants) are considered most important.

This study makes it clear that further R&D is needed to improve the catalytic activity of available materials and to create novel, more effective catalysts. Before field testing, improved meteorological simulations of smog formation, transport, and destruction will be needed to

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[4] Akbari, H., S. Konopacki, and M. Pomerantz. 1999. Cooling energy savings potential of reflective roofs for residential and commercial buildings in the United States. *Energy* 24:391–407.

[5] Konopacki, S., and H. Akbari. 2001. Measured Energy Savings and Demand Reduction from a Reflective Roof Membrane on a Large Retail Store in Austin. Lawrence Berkeley National Laboratory Report No. LBNL-47149, Berkeley, CA.

[6] Parker, D. S., et al. 2002. Comparative Evaluation of the Impact of Roofing Systems on Residential Cooling Energy Demand in Florida. *Proc. 2002 ACEEE Summer Study on Energy Efficiency in Buildings* Vol. 1, p. 219. Pacific Grove, CA.

[7] A. H. Rosenfeld et al. 1998. Cool Communities: Strategies for Heat Islands Mitigation and Smog Reduction. *Energy and Buildings* 28:51–62.

determine how to best deploy and use photocatalytic oxidation technology. In addition, further study is needed to ensure there are no unintended environmental consequences from the use of these catalysts, such as runoff of any undesirable reaction products into the water system.

Final Report

The final report for this project can be downloaded from www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2007-112.

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